Integrated Microfluidic Fuel Processor for Miniature Power Sources

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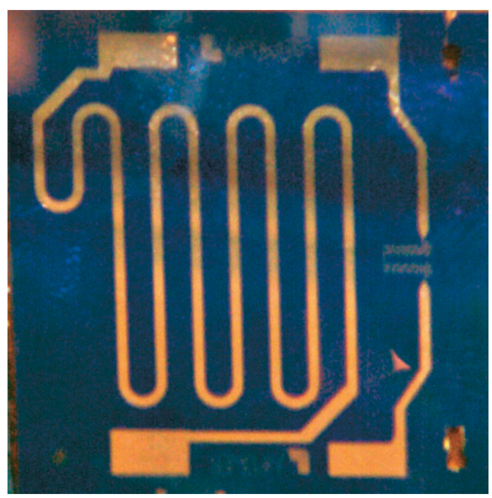
Improving portable power sources is a critical issue for the military, weapons-testing monitors, and the intelligence community. Commercially available batteries are inadequate for advanced applications in remote reconnaissance, intelligence gathering, and telemetry. Such applications require lighter-weight, longer-lasting power sources meeting specific performance criteria. Current proton-exchange (PEM) fuel cells are limited to 3 to 15% methanol solution, which restricts power and energy density. We are developing a PEM fuel cell with a separate microreactor that converts the methanol to hydrogen, thus exploiting the very high energy densities of methanol and other liquid fuels.

The objective of this project is to demonstrate the feasibility of a packaged microfluidic fuel processor with improved catalyst and integrated thermal management for waste-heat recovery or heat conservation through improved arrangements of heat exchanger and insulation. The project combines experimentation with theoretical and numerical analysis, design, and development and leverages LLNL's expertise in microfluidic devices, microfabrication techniques, and materials science. By delivering a reliable, long-lasting, miniature power source for military and intelligence applications such as sensors—a field in which long-lasting power sources are greatly needed—this work supports LLNL's national security mission. Farther in the future, applications could include long-lasting, lightweight power sources for a wide range of consumer electronics products, such as cell phones and laptop computers.

The power supply we are developing is a catalytic microchannel reactor based on the steam reforming of methanol, in which a mixture of water (H_2O) and methanol (CH_3OH) is heated to produce hydrogen gas (H_2) and carbon dioxide (CO_2) at ~300°C in the following reaction: $CH_3OH + H_2O \rightarrow CO_2 + 3\ H_2$. [Some methanol decomposes into carbon monoxide and hydrogen ($CH_3OH \rightarrow CO + 2\ H_2$), but a goal of catalyst optimization is to minimize decomposition.] The hydrogen fuel and the carbon dioxide byproduct are then delivered to the fuel cell manifold by microfluidic interconnects. With adequate catalyst surface area and applied heat, the microfluidic reformer produces hydrogen with only minimal power input needed to sustain the reaction. This system is thus an integrated solution that solves the issues of fuel storage, processing, and delivery.

In FY02, we developed reactor models based on published kinetics, achieving excellent agreement with our data, performed experiments using our microreactor (see figure) with two commercial catalysts containing copper oxide (CuO) and zinc oxide (ZnO) on alumina (Al_2O_3) and achieved methanol conversion rates of 80 to 96% at 250 to 300°C, which corresponds to electrical power of 500 to 1000 mW; successfully deposited sputter-coated nickel (Ni) and CuO catalysts on microchannels and nanoporous membranes; and built and operated a PEM fuel cell fed directly by the reformate hydrogen gas and yielding up to 150 mW of electrical power—our goal is to exceed 500 mW. Byproducts of this work to date are techniques for depositing active catalysts on microdevices and metallic sponges with very high surface area, which may be excellent catalysts for some applications. Other byproducts will include methods for feeding microreactors with very small but steady flow rates of liquid fuel, and methods to obtain very large thermal gradients external to the integrated devices. The results of this project were featured in two conference presentations, will soon appear in several peer-reviewed journals, and are expected to lead to one or more patents.

Our key objective for FY03 is to determine the best components and design for our microfluidic fuel processor so that a preprototype power module can be developed. For example, the appropriate catalyst (Ni or CuO/ZnO) and reactor configuration (microchannel, nanoporous membrane, or a combination of the two) will be chosen. Our project will also investigate how best to implement the thermal integration between the reactor inlet and the outlet, as well as how to integrate our microreactor with an operating fuel cell.



Photograph of a microreactor (approximately 1 in. square) capable of converting a liquid fuel such as methanol to hydrogen. Using a commercially available copper oxide–zinc oxide catalyst, the microreactor achieved energy conversion rates of 80 to 96% at 250 to 300°C, which corresponds to electrical power of 500 to 1000 mW.